1st Forum of Young Researchers in Energy & Environment

Thermal Energy Storage and Fuel Production

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Solar Rotary Kiln for Thermal Storage Applications

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Agenda

- Introduction: why a solar rotary kiln?

- Experimental demonstration for thermal storage applications
    - Solar thermal reduction of metal oxides

- Solar reactor adaptation for other thermochemical processes
    - The window problem

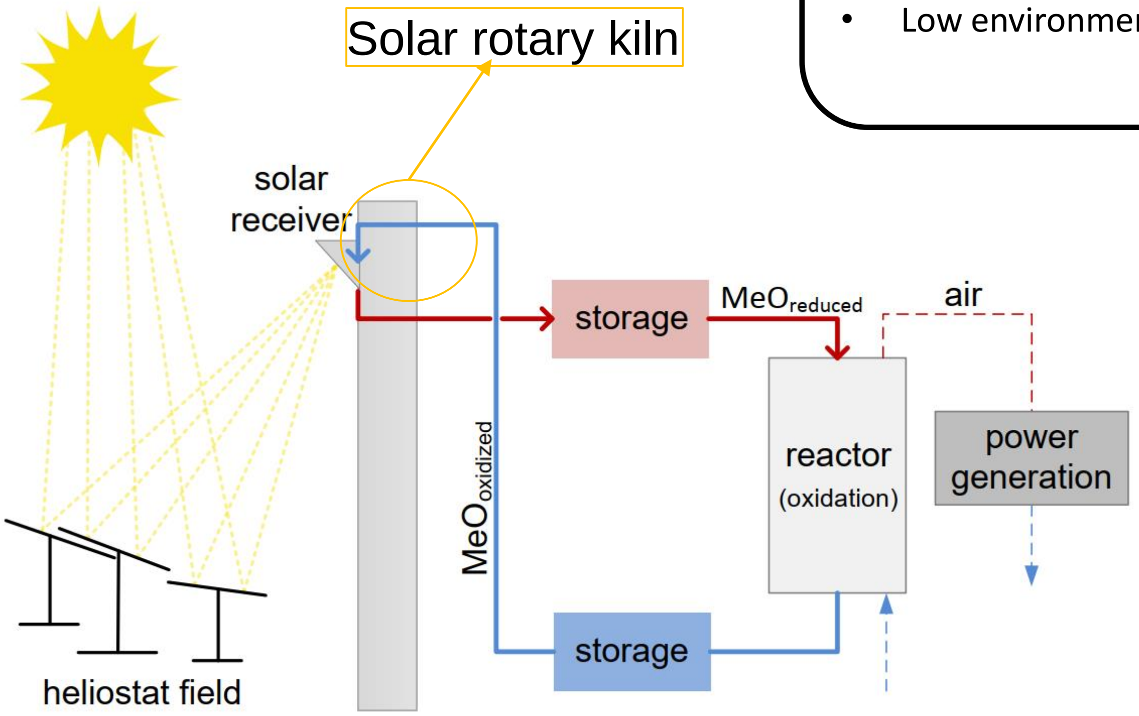
Introduction – thermochemical storage for CSP applications based on redox-reaction

- Concept of RedoxStorE cycle

$$6(\mathrm{Mn,Fe})_2\mathrm{O}_3 + \Delta_R\mathrm{H} \leftrightharpoons 4(\mathrm{Mn,Fe})_3\mathrm{O}_4 + \mathrm{O}_2$$

Material requirements:

- Mechanical strength & particle stability
- Chemical reversibility of redox reaction
- Affordable raw material cost
- Low environmental impact



2020, Preisner et al.

Introduction – why a solar rotary kiln?

Some reactor concepts for continuous solid-gas processes

- Moving bed
- Circulating fluidized bed
- Entrained flow
- Rotary kiln

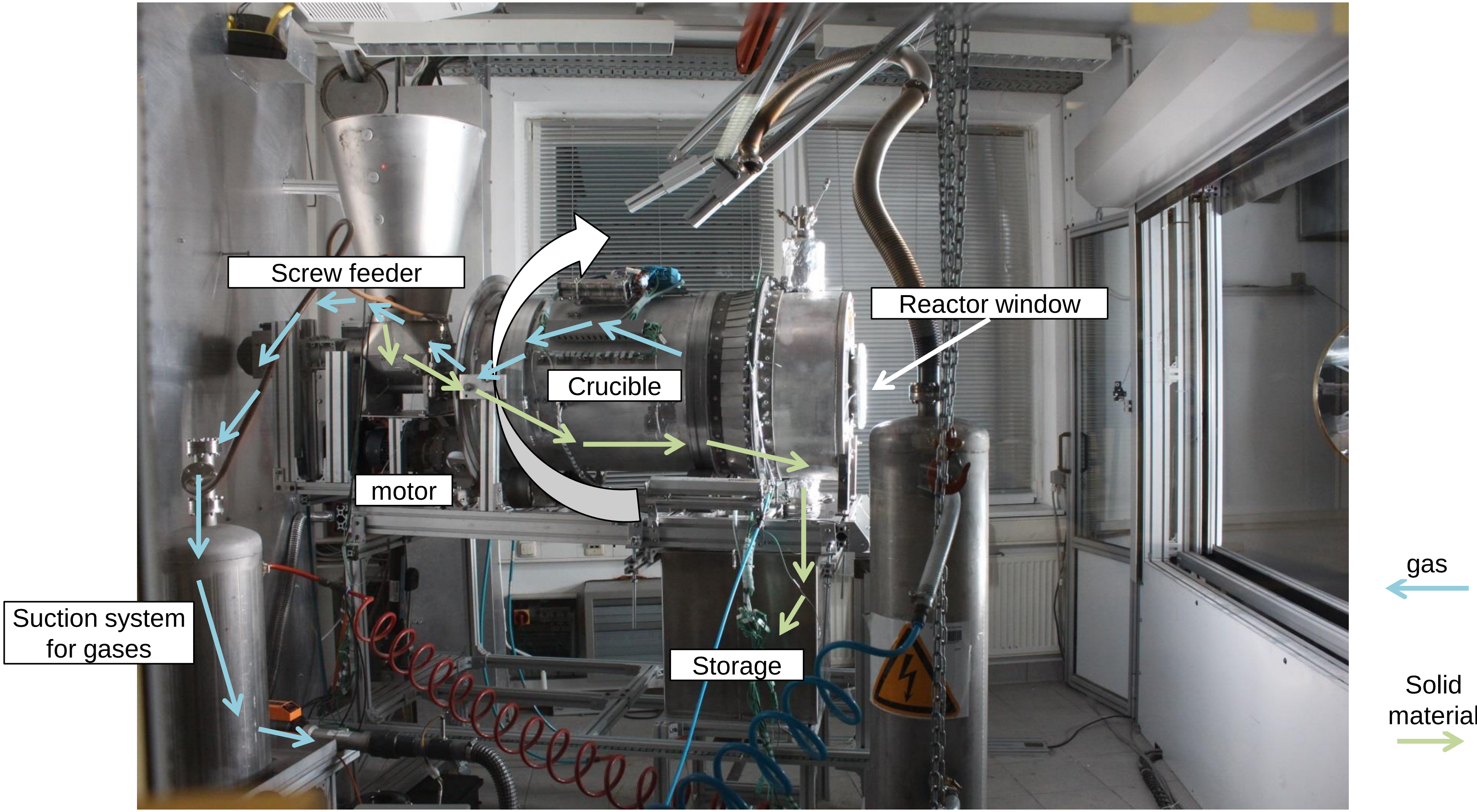
For solar applications **direct heating of particles** is possible

- Lower temperatures are needed
- If material sticks to the wall → ΔT between external reactor wall and particles can be avoided

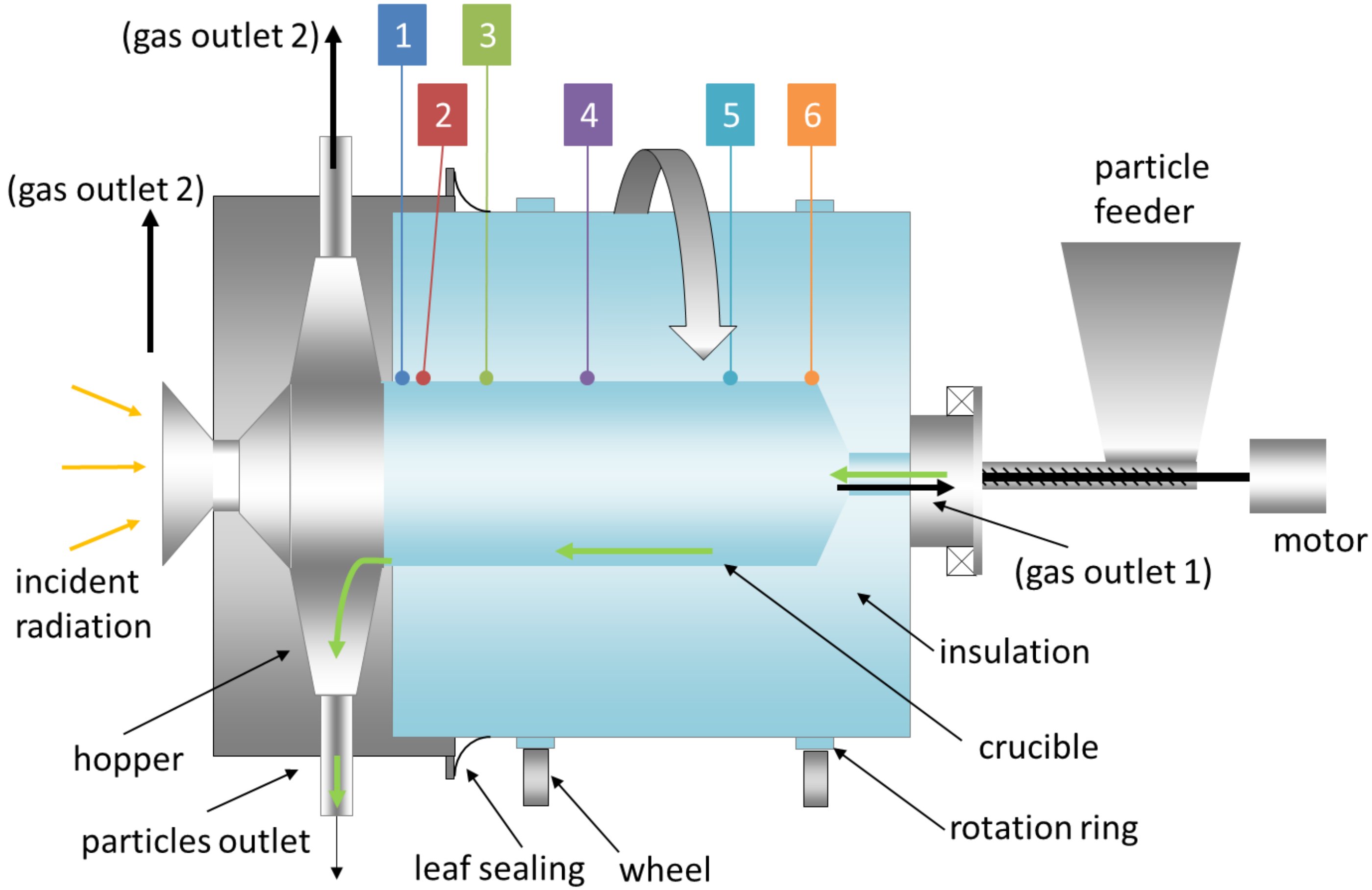
Wider range of particle size (from micro- to milimeter)

Used in big-scale industrial processes: cement industry

Introduction – solar rotary kiln reactor at the DLR



Experimental demonstration for thermal storage applications – solar thermal reduction of metal oxides

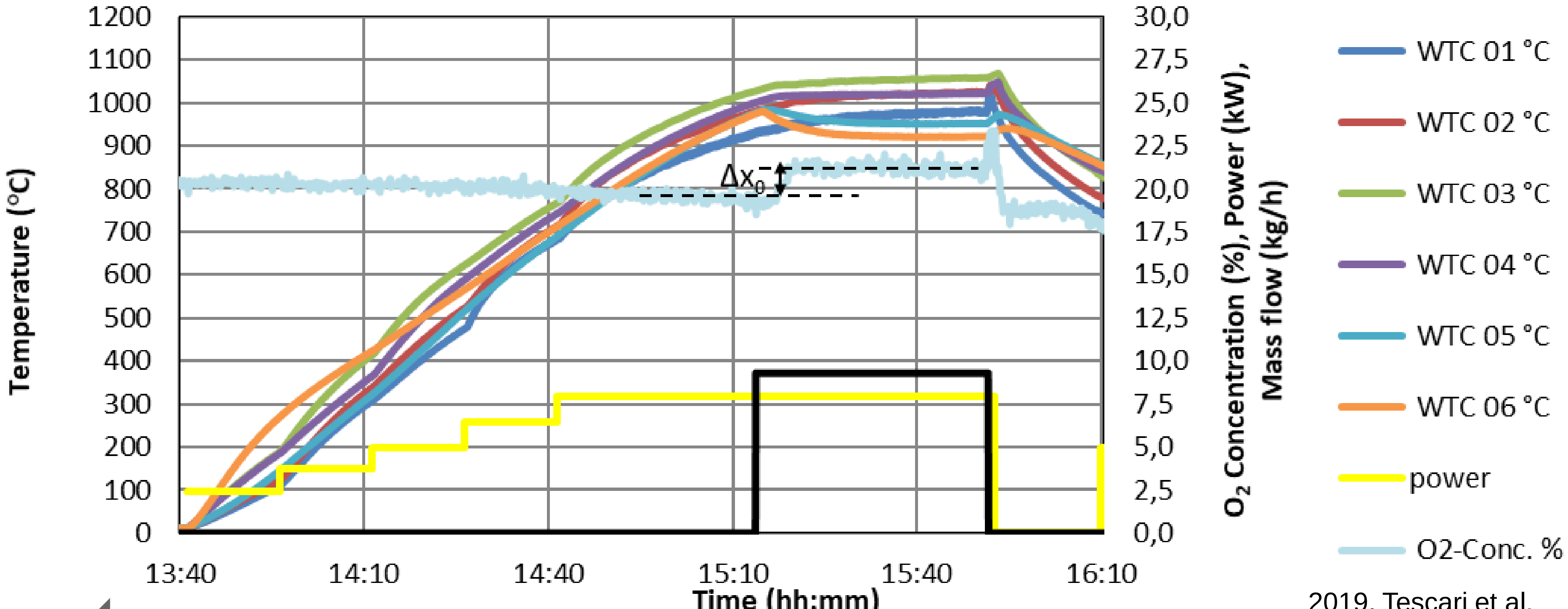


2019, Tescari et al.

Experimental demonstration for thermal storage applications – solar thermal reduction of metal oxides

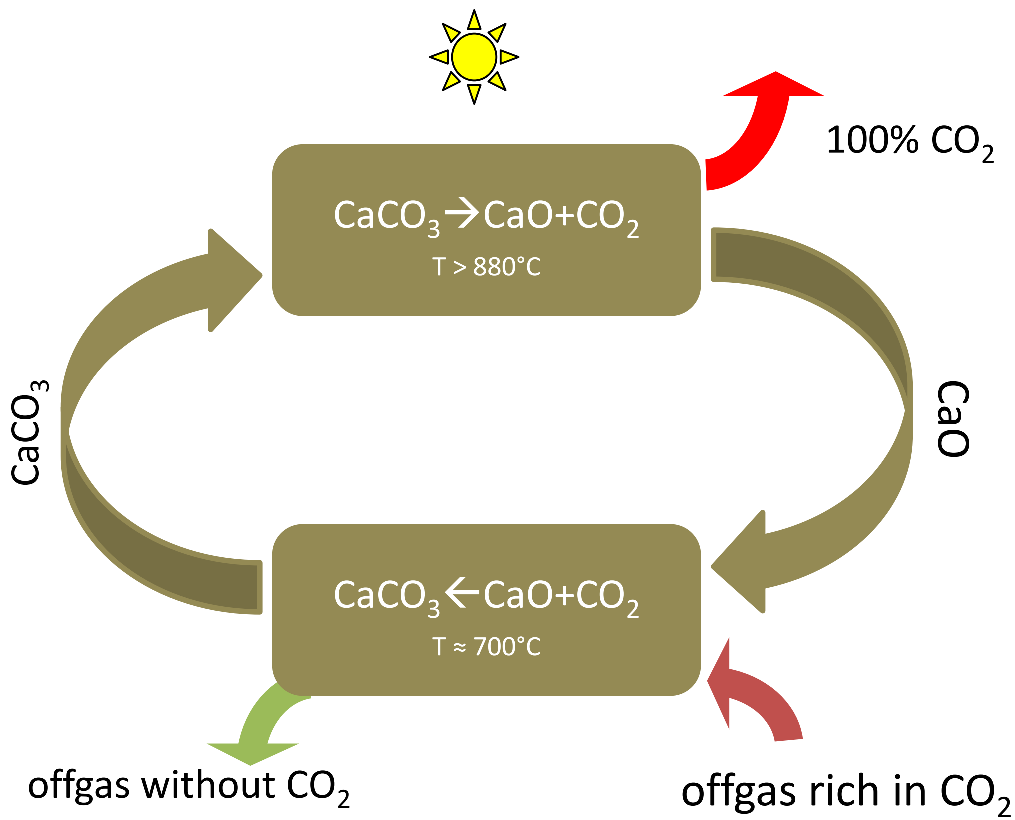
- $d_p = 2 - 3\ \mathrm{mm};\ \dot{m}_p = 9.2\,\frac{\mathrm{kg}}{\mathrm{h}}$
- $T_{red} = 1050°C;\ \ T_{deact} = 1100°C$
- $\mathbf{T_{max-react} = 1058°C}$
- Incident power: $8\ \mathrm{kW} \rightarrow 6$ lamps

$$6(\mathrm{Mn,Fe})_2\mathrm{O}_3 + \Delta_R H \leftrightharpoons 4(\mathrm{Mn,Fe})_3\mathrm{O}_4 + \mathrm{O}_2$$



2019, Tescari et al.

Solar reactor adaptation for other thermochemical processes – Solar CaO looping cycle



CO_2 capture from chemical reaction
→ closed reactor is needed

Material deposition on the window

carbonation step: CO_2 is captured, but also the energy from the exothermal reaction can be used

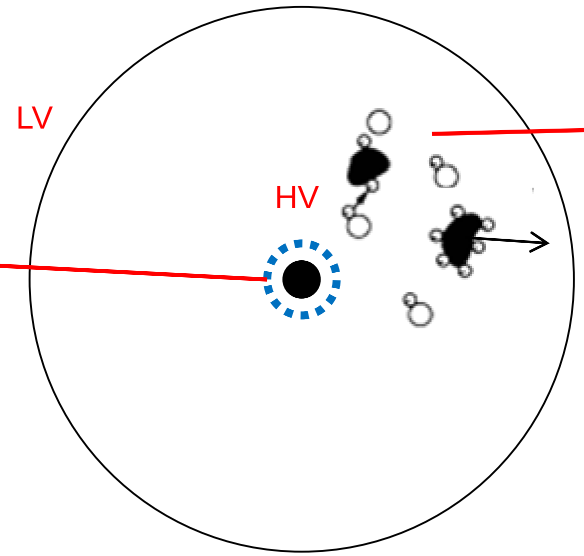
Solar reactor adaptation for other thermochemical processes – How to avoid the window problem?

Technology requirements for Solar reactors:
No interference of solar radiation, high T, avoiding T-gradients generation, reactor efficiency.

Window protection systems using injection of gas flows implemented:
Kogan, Z'Graggen, Koepf, Chinicci.
Problem not solved for rotating gas-solid reactors.

Electrostatic Separation of Particles ESP – wire-tube system

active zone:
high electric field region
Ionization of gas molecules
1 electron + 1 molecule → 2 electrons + 1 positive ion

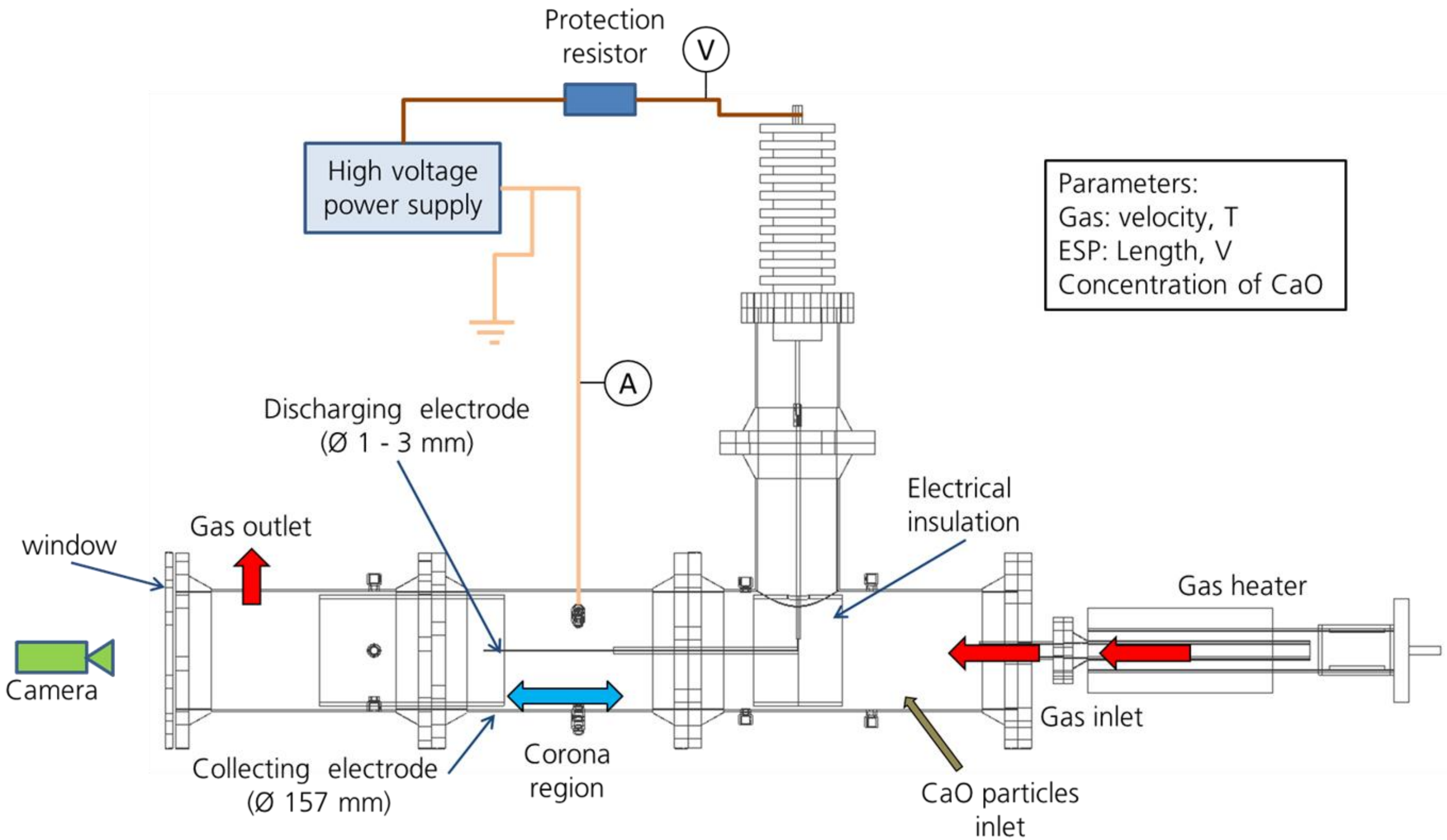


passive zone: low electric field region
Ionization of gas molecules
1 electron + 1 molecule → 1 negative ion

negative ions transfer its charge to solid particles
Particles migration to the collecting surface (LV)

Based on: 1996, Parker

Solar reactor adaptation for other thermochemical processes – ESP system to protect the reactor window

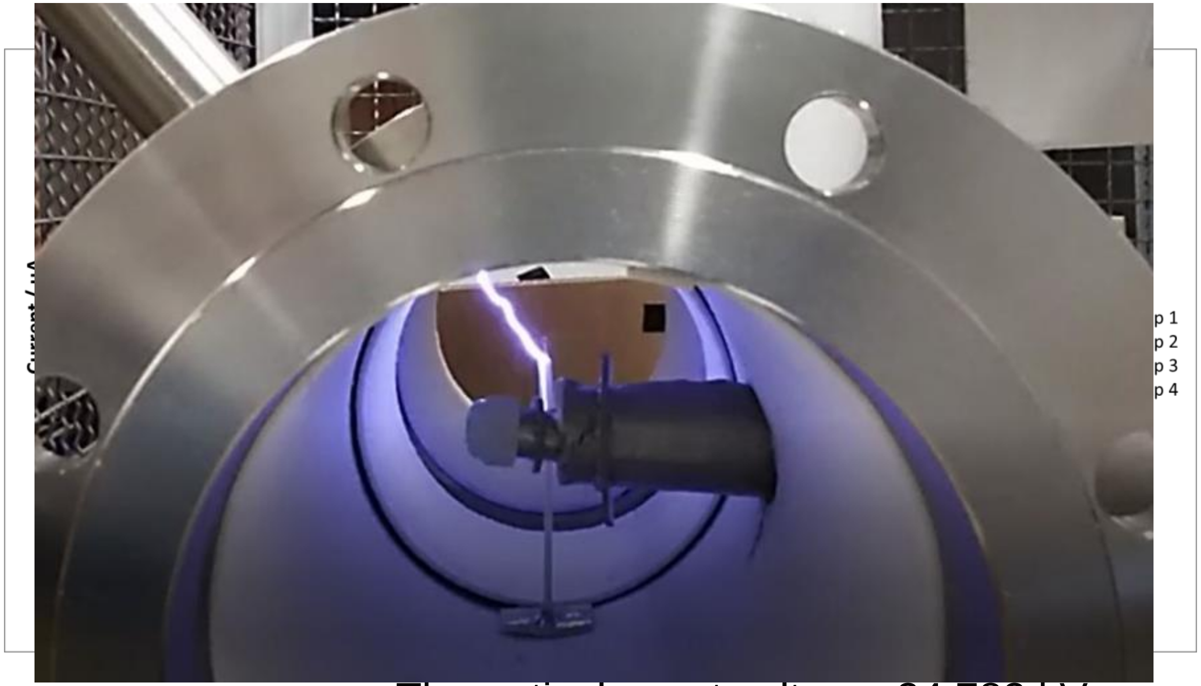


Challenge: high voltage combined with high temperature conditions

Solar reactor adaptation for other thermochemical processes – ESP system to protect the reactor window

The pipe diameter is similar to the diameter of the section of the rotary kiln where the ESP system will be installed.

Wire: 3mm; material 1.4841; tube diameter: 159 mm

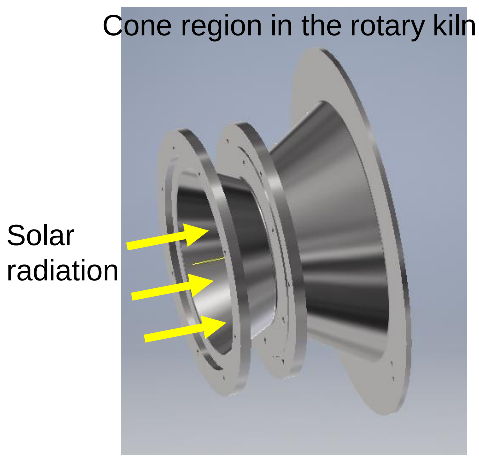


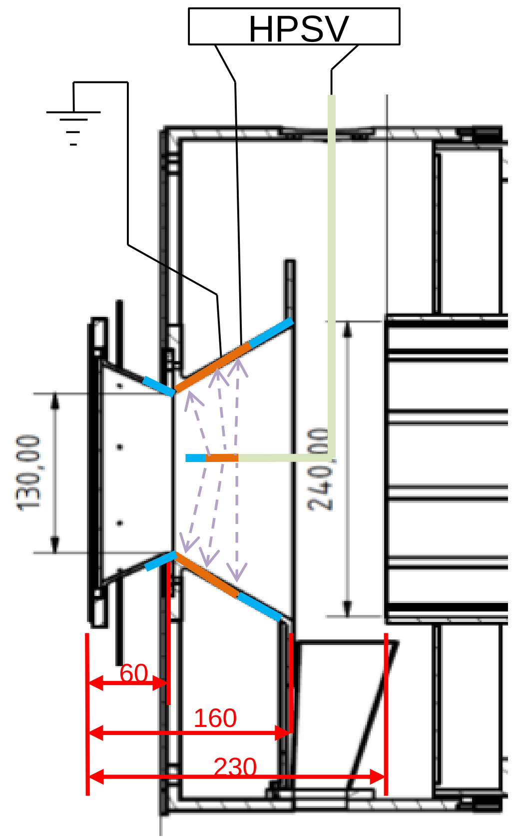
Theoretical onset voltage: 24.782 kV
Measured onset voltage: 25.3 kV

ESP operational gap $V_{spark} - V_{onset}$ decreases at high T → what is possible?

Outlook – Solar reactor adaptation for other thermochemical processes

- Investigation of high temperature ESP for several solar thermochemical processes
- System implementation in the solar rotary kiln reactor





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Thanks for your attention!

Questions?

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